Josephson Junction Arrays on the Basis of Superconducting PtSi Films

Tatyana I. Baturina [a,1], D.W. Horsell [b], D.R. Islamov [c], I.V. Drebushchak [c], Yu.A. Tsaplin [c], A.A. Babenko [c], Z.D. Kvon [a], A.K. Savchenko [b], A.E. Plotnikov [a]

[a] *Institute of Semiconductor Physics, 13 Lavrentjev Ave., 630090, Novosibirsk, Russia*

[b] *School of Physics, University of Exeter, Stocker Road, Exeter, EX4 4QL, U.K.*

[c] *Physics Department, Novosibirsk State University, 2 Pirogova str., 630090, Novosibirsk, Russia*

Abstract

We present the results of low-temperature transport measurements on Josephson junction arrays fabricated on the basis of superconducting polycrystalline PtSi films of thickness 6 nm. To fabricate a two-dimensional array of superconductor–normal-metal–superconductor Josephson weak links, we patterned a square lattice of holes with a period of 600 nm by means of electron lithography and subsequent plasma etching. A periodic variation of the resistance of these arrays with a period corresponding to the magnetic flux quantum per unit cell, including a secondary minimum at the half-quantum points, has been observed.

Key words: Josephson junction arrays; Superconducting films

Mesoscopic systems consisting of a normal metal (N) or heavily doped semiconductor in contact with a superconductor (S), have attracted an increased interest mainly because of the richness of the quantum effects involved. Among many systems of this type, arrays of Josephson junctions take a unique place as they are extremely useful model systems for studying phase transitions in frustrated and random systems, dynamics in coupled nonlinear systems, and macroscopic quantum effects [1]. Until now, Josephson junction arrays have been made by a combination of different materials. In our experiments the weak links are formed by constrictions within the original superconducting material.

The design of our samples is based on the fabrication technique, which we recently proposed and realized for the preparation of single SNS junctions and arrays of SNS junctions [2,3]. Suppression of superconductivity occurs in submicron constrictions made in an ultrathin polycrystalline PtSi superconducting film, and we use this fact now to prepare Josephson junction (JJ) arrays.

The original PtSi film (thickness – 6 nm) was formed on a Si substrate. The film was characterized using Hall bridge 50 μm wide and 100 μm long. The film had a critical temperature $T_c = 0.56$ K and the resistance per square was 104 Ω. The carrier density obtained from Hall measurements was $7 \cdot 10^{22}$ cm^{-3}, corresponding to a mean-free path $l = 1.2$ nm and a diffusion constant $D = 6$ cm$^2 s^{-1}$, estimated using the simple free-electron model.

To fabricate a JJ array we patterned a square lattice of holes covering the whole Hall bridge by means of electron beam lithography and subsequent plasma etching. A micrograph of the array is shown in the inset to Fig. 1. The JJ array is a lattice of constrictions connected by islands of the film. The lattice constant is 600 nm and the hole diameter is approximately 200 nm. The resistance versus temperature and magnetic field measurements were performed in a temperature-stabilized dilution refrigerator. A magnetic field was applied perpendicular to the film. Four-terminal transport measure-

[1] Corresponding author. E-mail: tatbat@isp.nsc.ru

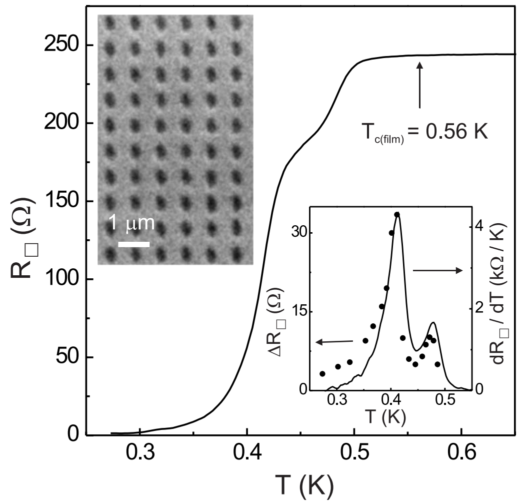

Fig. 1. Temperature dependence of the resistance of the Josephson junction array at zero magnetic field. The critical temperature of the original film is shown by the arrow. The upper inset presents a SEM subimage of the square lattice of holes made in the film (holes are dark, and the film is gray). The lower inset: Comparison of the observed temperature dependences of the amplitude of the periodic resistance change ΔR (from dependences $R(B)$ shown in Fig.2) and of dR/dT.

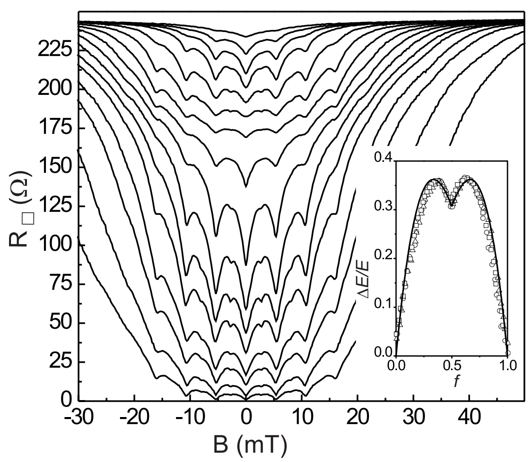

Fig. 2. Magnetic field dependence of the resistance at different temperatures within the range $0.273 < T < 0.494$ K. The inset shows the theoretical periodic dependence (solid line) on the magnetic flux per unit cell of the fractional reduction in average coupling energy, as given by Eq.(3) in [4], and the experimental data of magnetoresistance (symbols) at temperatures 0.38, 0.39, and 0.40 K.

ments were performed using standard low-frequency technique. The resistance was measured at a frequency of 10 Hz with an ac current of 10 nA.

Figure 1 shows the temperature dependence of the resistance of the structure under study. The initial drop of R at $T \approx 0.49$ K, which is less than the critical temperature of the unprocessed film, can be related to the onset of superconductivity in the islands of the film. With further decrease of T, the decrease of the resistance initially slows down and then rapidly drops towards zero. The "tail" is a manifestation of the Kosterlitz-Thouless transition.

The magnetic field dependences of the resistance shown in Fig. 2 represent the key data of this paper. These data prove that we are dealing with a JJ array. As is expected, at the temperatures less than 0.45 K the magnetoresistance oscillates with a period of one flux quantum per lattice cell ($\Delta B = \Phi_0/a^2$, where $\Phi_0 = h/2e$). Furthermore, the curves show a secondary minimum at $f = 1/2$ (f is the fractional number of flux quanta per lattice cell). The shape of oscillations qualitatively follows the magnetic field dependence of the average fractional reduction of the coupling energy, Eq.(3) in [4] (the inset to Fig. 2). Comparison of the amplitude of the periodic resistance variations with dR/dT also support the simple model proposed in [4]. More interestingly, in addition to the above features, Fig. 2 shows the apparition of large magnetoresistance oscillations in the temperature region of the initial decrease of the resistance ($0.47 < T < 0.49$ K), where fluctuation superconductivity exists only. These oscillations are superimposed on a background of positive magnetoresistance and can be attributed to the quantum interference effect (the AAS effect [5]) in the superconducting fluctuation regime, with the main contribution to the conductivity being the Maki-Thompson correction [6].

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